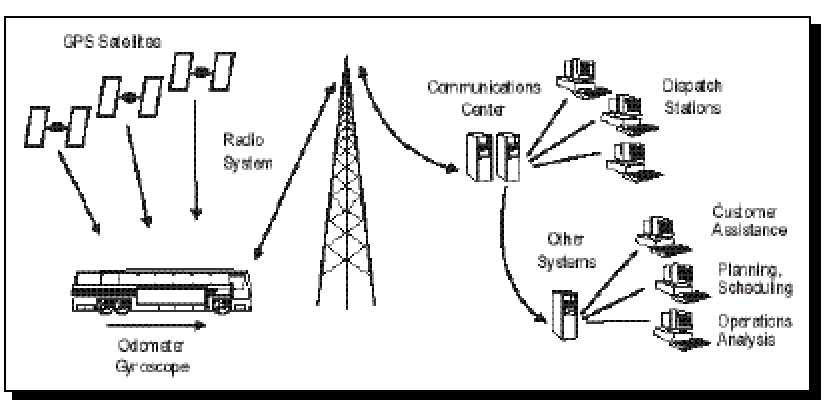
Automatic Vehicle Location

INTRODUCTION

What is Automatic Vehicle Location?

Automatic vehicle location (AVL) is a computer-based vehicle tracking system. For transit, the actual real-time position of each vehicle is determined and relayed to a control center. Actual position determination and relay techniques vary, depending on the needs of the transit system and the technologies employed. Typically, vehicle position information is stored on the vehicle for a time, which can be as short as a few seconds or as long as several minutes. Position information can be relayed to the control center in raw form or processed on-board the vehicle before its transmission. See our Telecommunications Diagrams of GPS-based AVL and Signpost-based AVL for more information.



Transit agencies often incorporate other advanced features in conjunction with AVL implementation. AVL systems normally include the following components:

• Computer-aided dispatch software
• Mobile data terminals
• Emergency alarms
• Digital communications

More sophisticated AVL systems are often integrated with the following components:

• Real-time passenger information
• Automatic passenger counters
• Automated fare payment systems
• Automatic stop annunciation
• Automated destination signs
• Vehicle component monitoring
• Traffic signal priority

The Rationale for AVL

Four prime objectives for the introduction of AVL have been identified by transit agencies in the U.S.: improved schedule adherence and timed transfers, more accessible passenger information, increased availability of data for transit management and planning, and the efficiency/productivity improvements in transit services. These objectives can be met with AVL since it increases the firm's capability to monitor information on vehicle position and operational status. By utilizing AVL, firms can increase fleet utilization and reduce input factors such as fuel, labor and capital. Revenue planning and efficiency can be improved through the use of on-board electronic fare collection. This can also provide for seamless transfers by implementing/supporting a common or universal fare medium (e.g. a fare card that is accepted by all operators in a defined region). AVL can also help improve safety on-board vehicles by allowing quick location and response to incidents and emergencies.

SYSTEM DESCRIPTION

Vehicle Location Technologies

Starting in 1969, transit agencies in the U.S. have experimented with various AVL systems. There are four basic technologies employed for AVL systems. In some cases, two technologies are used to create redundancy in the system. The most common technologies are:

- Signpost and odometer
- Radio navigation/location
- Dead-reckoning
- Global Positioning System (GPS Satellite Location)

<u>Signpost/odometer Systems</u>
The signpost/odometer system has been the most common until recently. In this system, a receiver is mounted on the bus, while transmitters are placed along the bus' route. Utility poles

and signposts are most commonly used as mounting locations for these transmitters. The bus picks up a low-powered signal from these transmitters as it passes by, and the mileage noted. When the bus reports its location, the distance from the last pole is used to locate the vehicle's position on a route. The system can be run in reverse, with the transmitter on the bus and multiple receivers mounted along the route. However, should the bus need to leave the route, there will be no information about the bus, so most agencies prefer to have a receiver on the bus. This older technology has some drawbacks. Creation of new routes requires the placement of new transmitters, and the system is maintenance intensive due to the relatively high number of transmitters and receivers involved.

<u>Radio navigation/location</u>
Radio-location systems use a low-frequency signal to cover the system, and the buses are located as they receive the signal. Loran-C (Long Range Aid to Navigation) is the most common type of land based radio location. Despite the simplicity of the system, it is subject to some major drawbacks. Overhead power lines or power substations can cause signal interference, and signal reception is typically very poor in canyons.

<u>Dead-reckoning</u>
Dead reckoning is among the oldest navigation technologies. Dead reckoning sensors can measure distance and direction from a fixed point (under the most basic setup, an odometer and compass could be used to calculate position from a specific stop on a route). Typically, these systems act as a backup to another AVL system. This relatively inexpensive system is self-contained on the bus. This system has a number of drawbacks. Uneven surfaces and hills can compromise the positioning information. Should the vehicle leave a fixed route, its location will no longer be known since there will be no waypoints off the fixed route. Also, accuracy degrades with distance traveled, and regular recalibration is required (tire circumference changes with wear).

<u>Global Positioning System</u>
Due to the shortcomings of the other AVL technologies, GPS became the most popular system for new installations over the last few years. GPS utilizes the signals emitted from a network of 24 satellites, which are picked up by a receiver placed onboard the bus. The satellite system covers almost all of North America, eliminating the need to place transmitters/receivers along any route. The existence of the satellite system means that the main cost for the agencies result from purchase of the GPS receivers and equipment to transmit to dispatch. While the U.S. military, which oversees the satellite system, has limited the accuracy of the system in the past, it is now allowing more accurate readings. The accuracy and reasonable cost of GPS makes it the most appealing, though it too has some problems. Foliage, tall buildings, and tunnels can temporarily block the satellite signal, and at times satellite signals do not reach specific locations. Typically dead reckoning is used in conjunction with GPS to fill in such gaps.

Alternatives to GPS
In recent years, competing terrestrial positioning technologies have emerged as viable alternatives to GPS. One such technology is Europe's Global Navigation Satellite System (GNSS), also known as Galileo. Galileo could eventually allow Europe to discontinue its dependence on the US GPS and Russian GLONAS systems. Galileo will be under civilian control and will allow positions to be determined accurately for most places on Earth, even in high rise cities where buildings obscure signals from satellites low on the horizon. This is because there will be twice as many satellites available from which to take a position. By placing satellites in orbits at a greater inclination to the equatorial plane than GPS, Galileo will achieve

better coverage at high latitudes. This will make it particularly suitable for operation over northern Europe, an area not well covered by GPS.

Data Transmission to Dispatch

The two most common methods of transmitting bus location data to dispatch are through polling and exception reporting via wireless communications. Under polling, the computer at dispatch operations polls each bus, in turn, asking for its location. This method requires the bus to be able to read or calculate its position. The bus location is then transmitted by radio to the dispatch center. Once all the buses have been polled, the computer starts again with the first bus and repeats the cycle. The amount of time it takes to complete a cycle will increase as the number of buses to be polled increases. However, because the computer can poll different buses simultaneously over different radio channels, the time to complete a polling cycle depends on the number of radio channels that are utilized. Most agencies employing polling query the buses at fixed intervals. In exception reporting, each bus reports its location to dispatch at only a few specified locations or where the bus is running off-schedule beyond selected tolerances. Exception reporting makes more efficient use of available radio channels, which are often scarce commodities. Many agencies use a combination of polling and exception reporting.

Data Use at Dispatch

AVL information is typically sent to a pair of personal computers (PCs) at the dispatch office. One computer serves as the communication machine, making contact with the buses. The second PC will usually map the vehicles' location on the network. It is important to realize that proper use of mapping software like a geographic information system (G.I.S.) is required in order to display this information effectively. This is a concern for many agencies with limited technology resources at their disposal. Many agencies have neither the money for additional equipment, nor for the trained personnel required. Training of employees is a key to maximizing the use of an AVL system. These PCs help anticipate and address bus failures, monitor schedule adherence and emergency response, and they can trigger location specific audio and visual announcements to comply with the Americans with disabilities act (ADA).

ASSESSMENT

Key Results

Starting in the early nineties, there has been a significant shift from odometer and signpost systems to Global Positioning System technologies. The dominant AVL technology deployed today is GPS, representing close to 75% of all systems deployed. Research (Gillen et al., 2000) indicates that there is currently no clearly superior technology (in terms of transit firm productivity) therefore the relative cost of comparable AVL systems should be the main consideration in selecting a system. However, GPS may become a more cost-attractive option in the near future as the U.S. Government stopped the intentional degradation of GPS signals available to the public starting May 1, 2000.

Recent evidence indicates that AVL technology is leading to significant transit firm productivity gains as well as increases in transit ridership. AVL technology allows: improved schedule adherence and timed transfers, more accessible passenger information, increased availability of data for transit management and planning, and efficiency/productivity improvements in transit services.

AVL also creates many possibilities for ITS systems integration including: providing transit buses with traffic signal priority; incorporating transit information in traveler information systems; developing multi-application electronic payment systems and using buses to automatically communicate traffic speed.

California PATH researchers have developed a framework for estimating the benefits and costs of AVL (chapter 5 of linked report).

Benefits

The most extensive and rigorous research into the benefits of AVL (Gillen et al. 2000) has found that this technology has lead to significant transit firm productivity gains (whether output is measured by Passenger Miles or Vehicle Revenue Miles). Benefits have been documented to varying degrees for all of the following categories:

- Operations:
    - Transit firm productivity gains: increased passenger trips, capital savings (potential reductions in fleet size due to better utilization of vehicles), lower annual maintenance costs and generally a lower vehicle cost per mile.
    - Improved schedule adherence, accuracy in schedule adherence monitoring and transfer coordination.
    - Increased transit ridership.
    - Labor savings: reduced need for additional road supervisors and manual data entry.
    - Improved ability of dispatchers to control bus operations as well as better monitoring of driver performance.
    - Effective tracking of off-route buses as well as paratransit vehicles and drivers.
- Communications:
    - Improved communications between supervisors, dispatchers, and operators.
    - Reduced voice radio traffic and loss of radio calls.
- Passenger Information:
    - Provides capability to inform passengers of predicted bus arrival times enhancing the quality of transit service and allowing travelers to make better travel decisions.
    - Reduces customer complaints and the need to add customer information operators.
    - Possibility to use AVL data to substantiate agency's liability position.
    - Improves image of agency.
- Scheduling and Planning:
    - Provides more complete and accurate data for scheduling and planning.
    - Potential reduction in schedule preparation time and staff.
    - Aids in effective but stop placement (when combined with a G.I.S. database and automatic passenger counters).
- Safety and Security:
    - Enhances driver and traveler security (particularly when coupled with silent alarm technology) by allowing quick location of vehicles and faster security response.

- Enhances driver and traveler safety: accurate and quick location information allows for faster response to accidents.
- Better operational response during detours caused by accidents, roadway closings or bad weather.

Costs

- Procurement costs to install the equipment and the software both on-board buses and at the operations/dispatch center.
- Labor: maintenance of on-board AVL equipment and operations center equipment, time required to learn new systems and new staff for software maintenance and at operations center.

The capital cost of an integrated installation of AVL and other advanced public transportation system components is dependent on the size of the system, its level of sophistication, and the components to be included. Systems can range from those with fairly basic features (GPS or DGPS AVL, computer-assisted dispatching, mobile data terminals, silent alarms, and limited automated passenger information) to very comprehensive systems. There is a significant cost for the equipment and software that reside at the operations/dispatch center. The per-bus cost of large fleets is less than for smaller fleets, assuming similar features, because the cost of this major infrastructure is distributed over a larger number of vehicles. Taking these factors into consideration the cost per AVL-equipped bus can range from $6,800 to $30,500, with an average cost of $15,500 per bus (FTA, ITS JPO August 2000, based on a survey of 6 transit agencies of varying size).

System Integration Opportunities

Having AVL-equipped buses offers many possibilities for transit interface with highway and traffic organizations or transportation management centers. Opportunities include: providing transit buses with traffic signal priority; obtaining traffic congestion data at the dispatch center to allow rerouting of buses or informing customers of delay; incorporating transit information in traveler information systems; developing multi-application electronic payment systems; using buses to automatically communicate traffic speed; and reporting of roadway incidents by transit vehicle operators.

Traffic signal priority on arterials and at freeway on-ramps can substantially improve the schedule adherence of transit vehicles and reduce run times. This effort requires cooperation between transit and highway departments because traffic signals are normally the responsibility of highway departments, and giving transit vehicles priority affects other vehicle movements.

Transit information should be an important element of any regional traveler information system. Adding real-time transit information to available highway information can be helpful to travelers in making mode choice decisions and would be expected to increase transit ridership.

Electronic fare payment may be one of the more appealing adjuncts to an AVL system for potential riders because of the convenience it offers the user. The greatest benefits of electronic payment systems would result from the inclusion of multiple transit agencies and integration with other activities, such as toll collection, and payment for parking and retail purchases.

AVL-equipped buses can be used as probes for determining travel speeds on freeways and arterial roadways—a valuable information resource for a transportation management center, especially one with limited traffic detection or observation capabilities, particularly on arterials. Bus operators can also be useful in reporting incidents they see during their trips. Using the known location of the bus at the time of an incident report, the response of arterial, freeway, and incident management systems and emergency services can be more quickly provided. Paratransit dispatchers would be able to more efficiently route their vehicles if they have real-time information on freeway and arterial speeds and incidents.

Implementation and Operational Challenges

Early adopters of AVL systems experienced many technical and institutional problems. The biggest challenge for agencies implementing AVL today is the potentially lengthy procurement and installation period (particualry software development and integration of technical components). For this reason, agencies procuring an AVL system may want to use an existing design, with customization capabilities. Such an approach would substantially limit potential risks and problems. Other implementation and operational challenges to consider are:

- Implementation:
  - Institutional relationships may be difficult.
  - Development of new software or extensive customization of existing software can result in many possible problems.
  - Considerable effort may be required to establish an accurate geographic information system database.
  - Systems should be consistent with the National ITS Architecture.
- Operations:
  - New technical expertise is usually required at the transit agency.
  - Some existing staff may be reluctant to learn the new technology.
  - The schedule adherence function design requires careful thought.
  - A global positioning system signal reception problem may occur in certain areas.
  - The huge volume of data that an AVL system can record may overwhelm existing agency analysis capability.

WHERE IS AVL IMPLEMENTED?

Simple AVL systems are implemented throughout the United States, Western Europe and in South East Asia. Comprehensive AVL systems are being implemented on a limited basis in the United States and Western Europe. However, comprehensive AVL systems are being increasingly deployed.

In the United States, a recent study has identified at least 61 transit agencies with operational AVL systems. A hundred others are in the planning or implementation stages. The locations of operational systems are indicated on the map (below). For identification of these transit agencies, as well as those in the planning or implementation stages, see the report Advanced Public Transportation Systems Deployment in the United States—Update January 1999, referenced at the end of this document.

Table 1 describes the different types of AVL technologies employed or in planning for differrent types of service in the United States.

Table 1: AVL deployment in the United States, January 1999

	By Transit Agency	By Service Type
Totals	154	224
Service Type		
FR		127
DR		75
LR		7
HR		3
CR		5
FB		6
AG		1
Technology (Primary)		
GPS/DGPS	107	157
SignPost/Odometer	14	18
Loran-C	1	1
Dead Reckoning	2	2
Other	4	4
Unknown	32	46
Status		
Operational	61	79
Implementation	25	33
Planning	75	116

FR= Fixed Route; DR= Demand Response; LR= Light Rail; HR= Heavy Rail;
CR= Commuter Rail; FB= Ferry Boat; AG= Automated Guideway; MR= Monorail.
Source: Advanced Public Transportation Systems Deployment in the United States—Update January 1999, FTA.

CASE STUDIES

Most of the following case studies are US-based and are excerpted from Advanced Public Transportation Systems, The State of the Art Update of '98 (ITS JPO, January 1998). For more examples of the use of AVL please refer to this document.

Signpost/odometer systems

Newark, New Jersey
New Jersey Transit (NJT) is implementing a new signpost and odometer system. The system will operate primarily in Essex County (Newark area), although all of their buses are equipped with the requisite hardware and software. Hardware implementation is about complete, including on - board equipment on all buses and signposts at every garage, at strategic places in Essex County, and at the Port Authority Bus Terminal in New York City, the terminus of many of their routes. NJT is now in the process of inputting all route data into the central computer and training their dispatchers on the use of the system. NJT notes that the software capabilities are now catching up to the hardware which has been available for a number of years. NJT is implementing the AVL system in order to better manage their bus operations.

Seattle, Washington
King County Metro has had an operational signpost and odometer AVL system on all of its buses since 1993. Original system cost was about $15 million. The system includes computer -assisted dispatching. Each bus has a mobile data unit (MDU) and silent alarm for the driver. Over the last two years, the AVL has been linked to automatic passenger counters, which Metro has been operating on 12 percent of its buses since 1980 (see Section 2.4). Previously, the APCs had their own location equipment. Now, the bus' MDUs are capable of feeding bus location information directly to the APCs, eliminating the need for a separate signpost network. The AVL also provides the information for "Bus View," a real-time passenger information system on the Internet (see Section 3.1) Bus View gives, in text form, bus schedules and vehicle status. Metro is also upgrading the CAD and AVL software, and is to have this completed by early 1998. Future system enhancements may include links to smart card readers on the buses, electronic fareboxes, electronic destination signs, and automatic vehicle identification tags. Metro cites th e benefits of AVL as an increased availability of operations data, a greater ability to respond to service disruptions and emergencies, and the ability to offer transfer protection to their riders.

Westchester County, New York
The Westchester County DOT (White Plains area) has been operating a signpost and odometer AVL system, including a silent alarm for the driver, on most of their 332 buses since 1983. The system has served the agency quite well, but the agency feels it is time to replace the system. The DOT has hired a consultant to conduct a review of the current conditions and interview th e personnel working on the AVL system. They expect to complete a system design by the end of 1997 and release a request for proposals sometime in the second quarter of 1998. The new system will (most likely) be GPS- based and will be designed to link into their two-way communications and the bus' "black box" (destination sign, farebox, etc.).

Norfolk, Virginia
Managing a fleet of 151 vehicles, Tidewater Regional Transit (TRT) elected to use a signpost/odometer AVL system in 1991. Their current system requests information from each vehicle in 40-second intervals. The system provides real-time information and provides more accurate schedules. TRT also added the silent alarm capability to the AVL system and vehicle condition monitoring sensors. TRT has benefited in lower rider complaints and an improved ability to respond to complaints.

GPS Systems

Portland, Oregon
The Tri-County Metropolitan Transportation District of Oregon (Tri-Met) is just finishin g installation of a GPS AVL system. All 640 of its fixed-route vehicles are equipped, and installation on its 140 paratransit vehicles, begun in September 1997, was to be complete within two months. Although they have not reached final acceptance, the fixed-route fleet is being dispatched using the AVL. The system also includes APCs (see Section 2.4) and real-time information for telephon e operators to respond to passenger inquiries. (Future plans call for providing the real-time information directly to the public, without the need for a human interface.) Three pilot tests of preferentia l treatment have been conducted and is now scheduled for permanent installation in a fifteen mile corridor. (Early buses will not receive preferential treatment.) The AVL is part of a regional ITS system, which is proceeding. Transit buses will be used as probes for traffic monitoring, and the highway department will provide the traffic information back to Tri-Met.

Denver, Colorado
The Regional Transportation District (RTD) has had an operational AVL system on all of its 900 buses since the end of 1995. AVL data are also used to post real-time departure information onsigns at the two Mall stations, downtown. The system, which cost about $11 million, includes an extensive computer-aided dispatch syst em. RTD feels that the AVL system gives them better control of the fleet, while freeing a number of on-street supervisors for other important duties. Schedule adherence is improved since the installation of AVL. Disabled buses can be located and serviced much more quickly. Also, one fewer person is necessary at the downtown Mall stations where many of their routes terminate.

The agency also believe s that AVL greatly heightens passenger safety. Police are now much more willing and able to respond to emergencies on buses, because the bus now can be located to within a few feet. Prior to the implementation of AVL, it could take a long time to locate the bus if it was off-route. In one situation, AVL greatly assisted RTD and the police in re-uniting a mother with her child which she had left behind on a bus.

Future plans center around use and dissemination of the bus location data. RTD is not currently using the schedule adherence function, nor are the AVL data being used by the scheduling department. This will happen when the schedule adherence function is working satisfactorily.

Current plans are to put passenger information data on the Internet. Additionally, there are information kiosks around the city, which may be fed AVL information in the future. Finally, there are plans to transmit the data to the Colorado DOT Traffic Operations Center for intermodal coordination of transportation in the region.17

Atlanta, Georgia
The Metropolitan Atlanta Rapid Transit Authority’s (MARTA) ITS system received fina l acceptance on March 30, 1997. Of the system’s 750 buses, 250 are equipped with AVL. The system is linked to the Georgia DOT’s traffic management center for inter-agency cooperation. Also, 15 buses are currently equipped with automatic passenger counters, and 60 more will be added in the near future (see Section 2.4). Some of the buses are equipped with on-board annunciators (automatically actuated by the AVL), and there are electronic signs at a few bus stops and monitors at some bus-rail transfer stations. Although the real-time bus location information is not yet fed into the many electronic passenger information kiosks around the city, they are hoping to do this soon.

MARTA is pleased wit h its AVL system and notes concrete benefits. They believe they can more effectively improve on- time performance with the greater information AVL provides. Another benefit is greater safety. For example, when an off-route bus had an accident, the dispatcher sent assistance directly to the bus' current location, even though the driver had identified the bus as still being on-route. Another instance involved a bus, making the last trip of the night from a rail station, left before its scheduled time. The dispatcher saw that the bus had left too early, and called it back to the rail station, so that the passengers exiting the train would not be stranded.

New York City, New York

In October 1996, New York City Transit (NYCT) awarded a contract for an 18-month demonstration project of an AVL system. The New York City environment also provides extremely heavy ridership, headwa y variability, and bus bunching, all of which have to be addressed in system design, installation, training, and operation. As of September 1997, the project had passed the critical design phase and had begun the construction and installation phase. The AVL will locate primarily by GPS, but will also rely heavily on interpolations between GPS signal receptions with dead -reckoning, due to the challenging environment of New York City. Tall buildings lining both sides of most streets make it difficult to obtain GPS signals, making position determinations by GPS less frequent.

Approximately 170 buses from the 126th Street depot in Manhattan will be equipped with differential GPS receivers and dead-reckoning technology, connected to mobile data terminals (from which the driver will receive information). Anticipated accuracy of the vehicle location is about ten meters. The on-board processor (vehicle logic unit) will store uploaded schedule information and will use time and locatio nal data to compute schedule adherence for both the driver and the dispatch center. Problems will be transmitted on an exception basis. However, a default polling interval of 40 seconds wi ll be used to provide the timely vehicle location data required by the custome r information system that is being developed simultaneously (see Section 3.2). Drivers will use a soft key vehicle control head to communicate both digital messages and requests to make voice contact over the upgraded 800 MHz radio network. Radio system upgrades include de-trunking of five of their 15 channels to provide dedicated channels for transmission of AVL data to the related CAD system (see Section 2.5.1). Archival data and reports will be used to optimize routes, schedules, and operations.

Dead Reckoning combined with another technology

Chicago, Illinois

CTA has a fleet of 2080 buses, which will all be AVL enabled. The system of choice for CTA is dead reckoning working alongside a GPS system. Both systems will transmit location information but one system will compensate for the other when a bus reaches an area where service for one system is interrupted. Tall buildings and underpasses made dead reckoning a viable complementary addition to GPS. The combination of the two systems also permits a high degree of accuracy in locating vehicles.

Houston, Texas

The Metropolitan Transit Authority (Metro) is planning to procure a full AVL system for all the vehicles it operates - 1,200 fixed-route buses, 153 demand-response vehicles, 154 police cars, 4 motorcycles, and 263 support vehicles. Previously, they awarded a $22 million contract for th e communications backbone, complete with a new radio system, and a vehicle area network, which complies with the J1708 standard, for their buses. (The installation of this backbone was to b e complete by January 1998.) The desired location method “is specified as dead-reckonin g supplemented with another proven location technology. Final determination of the ‘other’ [location technology] has not been made.”

The communications backbone is designed to support several other APTS applications. The base system will be linked to both the electronic farebox and the destination signs on the exterior of the bus. In addition, there is funding in place for the procurement of approximately 250 automatic passenger counters. Possible future additions to the system include annunciators and remote engine monitoring.

Ground-based Radio

Rochester, Pennsylvania
Beaver County Transit Authority uses a Motorola Loran-C system for 13 out of 36 buses in its fleet. The Loran-C system has resulted in better on-time performance and less rider complaints. BCTA installed Loran-C in 1991 and will now become a National Pilot Site for a Mobility Manager, which will update their AVL to a GPS enabled AVL system.

Santa Monica, California
The Santa Monica Municipal Bus Lines continues to employ an alternative form of vehicle location. As described in Update ‘96, the agency has had the AVL system in regular operation since October 1992. For $130,000, the agency purchased a workstation equipped with a modem, an electronic map with a detailed database of the streets and addresses in the Los Angeles area, and communications and control software. Buses are located by using a network of transmitting and receiving antennas.

The agency’s workstation communicates with the control center through standard telephone lines, and the agency pays a monthly subscription fee, based partly on the amount of time its workstation is connected to the central computer. The agency does not connect their workstation to the central computer too often, because the cost would be prohibitive. The AVL, therefore, does not operate in real-time. Santa Monica Municipal Bus Lines uses the information for planning and problem investigation only.

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This report excerpted several segments from references 1, 3 and 5.

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